EVALUATION OF OXYGEN AND CARBON CONTENT IN STANDARD FLOAT ZONE SILICON DETECTORS

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Carbon is one of the technologically important impurities in silicon and its behavior upon thermal and radiation treatments has been studied intensively for several decades [1].
It is well known that concentrations of oxygen and carbon in silicon crystals can be evaluated using annealing kinetics of interstitial carbon (C_i) [2-4]. However there are contradictory data on C_i capture radii by oxygen (r_{co}) and interstitial carbon (r_{cc}). The ratio r_{co}/r_{cc} has been determined to be equal to 1/3 in [2], 1 in [3,5] and 3 in [4]. Another result not fully understood yet is the scattering of activation energies for Ci annealing. They have been found to scatter from 0.73 eV [6] to 0.87 eV [7]. These findings make the treatment and modeling [7] of Ci annealing data to be ambiguous.

[1] G. Davies and R.C. Newman: *Handbook on Semiconductors*, edited by T.S. Moss (Elsevier Science, Amsterdam, 1994), Vol. 3b, p. 1557, and references therein.
[2] G Davies et al 1987 Semicond. Sci. Technol. 2 524.
[3] L.C. Kimerling et al., Material Science Forum, Vols. 38-41 (1989) p.141.
[4] V.P Markevich and L.I. Murin, Soviet Physics- Semiconductors, 1988 -Vol. 22, p. 574.
[5] J.L. Benton et al., MRS Symp. Proc. Vol. 104 (1988) pp.85-89.
[6] L.W. Song and G.D. Watkins, Phys. Rev. B 42, 5759-5764 (1990).
[7] A K Tipping et al 1987 Semicond. Sci. Technol. 2 315-317.
[8] B.C MacEvoy, G/ Hall, Mater. Sci. Semicond. Processing, 1 (2000) pp. 243-249.

DEFECT REACTIONS INVOLVED IN ANNEALING AND THE METHOD

First, it is the appearance of interstitial carbon in Si

$$C_s + Si_i \rightarrow C_i + Si_s$$

Reaction of mobile interstitial carbon with other impurities

$$C_i + O_i \rightarrow C_iO_i \qquad (1)$$

$$C_i + C_s \rightarrow C_iC_s \qquad (2)$$

$$C_i + P_s \rightarrow C_iP_s \qquad (3)$$

For weakly doped silicon ($P<10^{15}$ cm^{-3}) the 3rd reaction exerts no influence on C_i annealing rate.

$$\frac{d[C_i]}{dt} = \frac{[C_i]}{\tau_{ann}} \qquad (4)$$

$$\tau_{ann}^{-1} = \tau_{CO}^{-1} + \tau_{CC}^{-1} \qquad (5)$$

$$\eta = \frac{[C_iC_s]_{final}}{[C_i]_{initial}} = \frac{[C_s]}{[C_s] + \frac{r_{CO}}{r_{CC}}[O_i]} = \frac{\tau_{CC}^{-1}}{\tau_{ann}^{-1}} \qquad (6)$$

Results of previous studies

Results of the eighties

Table 1.

Experimental data on interstitial carbon lifetime limited by oxygen and carbon trapping

Research group	Trapping rate by 10^{16} cm^{-3} of O_i, τ^{-1}, s^{-1}	Trapping rate by 10^{16} cm^{-3} of C_s, τ^{-1}, s^{-1}	Ratio of capture radii, r_{co}/r_{cc}	Experimental method
Newman's (UK)	—	$6.9\cdot10^{9}\exp\left(-\frac{0.87}{kT}\right)$	1/3	IR absorption
Kimerling's (USA)	$5\cdot10^{8}\exp\left(-\frac{0.85}{kT}\right)$	—	1	DLTS
Murin's (USSR)	$1.35\cdot10^{8}\exp\left(-\frac{0.77}{kT}\right)$	$0.45\cdot10^{8}\exp\left(-\frac{0.77}{kT}\right)$	3	Hall-effect

Results of the nineties

Song and Watkins, 1990 have found in Si crystals with [Cs]=$1 \cdot 10^{17}$ cm^{-3} and[P]= $1 \cdot 10^{17}$ cm^{-3} that, first, C_i annealing is characterized by rather low activation energy 0,73 eV and, second, is dependent on minority carrier injection.

Abdulin et al., 1990 have found that C_iO_i is formed through intermediate stage:

$$C_i + O_i \rightleftarrows C_iO_i^* \rightarrow C_iO_i$$

Using this method Schmidt et al., 1994 have shown that oxygen is inhomogeneously distributed in processed detectors.

Table 2

Inverse lifetime data For $[O_i]$, $[C_s]$=1e16 cm^{-3}

T, °C	τ_{CO}^{-1}, s^{-1}			τ_{CC}^{-1}, s^{-1}		
	USSR data	USA data	UK data	USSR data	USA data	UK data
0	$8.3 \cdot 10^{-7}$	$1.0 \cdot 10^{-7}$	$2.0 \cdot 10^{-7}$	$2.8 \cdot 10^{-7}$	$1.0 \cdot 10^{-7}$	$6.1 \cdot 10^{-7}$
20	$7.8 \cdot 10^{-6}$	$1.2 \cdot 10^{-6}$	$2.5 \cdot 10^{-6}$	$2.5 \cdot 10^{-6}$	$1.2 \cdot 10^{-6}$	$7.6 \cdot 10^{-6}$
30	$2.1 \cdot 10^{-5}$	$3.7 \cdot 10^{-6}$	$7.9 \cdot 10^{-6}$	$7.1 \cdot 10^{-6}$	$3.7 \cdot 10^{-6}$	$2.4 \cdot 10^{-5}$
50	$1.3 \cdot 10^{-4}$	$2.8 \cdot 10^{-5}$	$6.2 \cdot 10^{-5}$	$4.4 \cdot 10^{-5}$	$2.8 \cdot 10^{-5}$	$1.9 \cdot 10^{-4}$
75	$9.6 \cdot 10^{-4}$	$2.5 \cdot 10^{-4}$	$5.8 \cdot 10^{-4}$	$3.2 \cdot 10^{-4}$	$2.5 \cdot 10^{-4}$	$1.75 \cdot 10^{-3}$

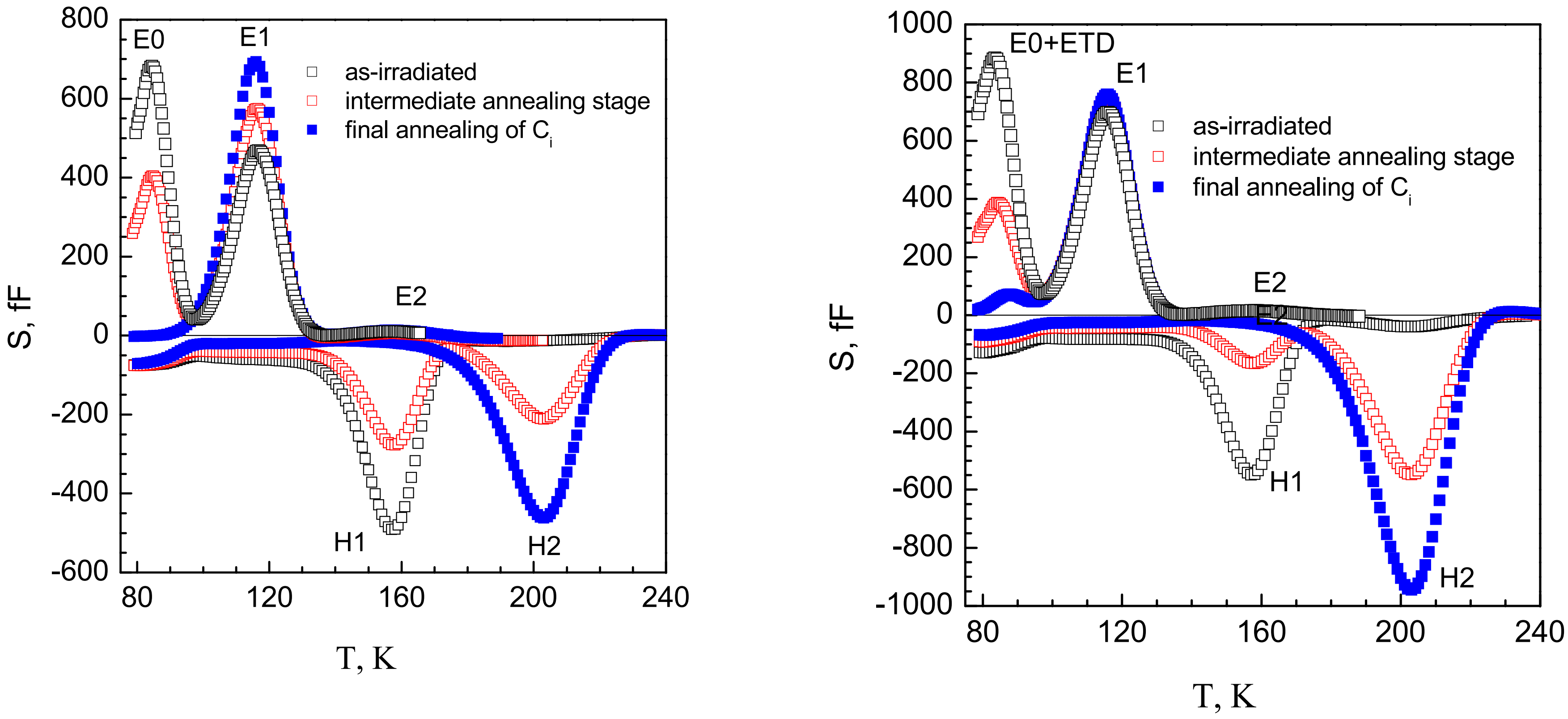

Fig. 1. DLTS spectra obtained for STFZ (a) and DOFZ (b) detectors

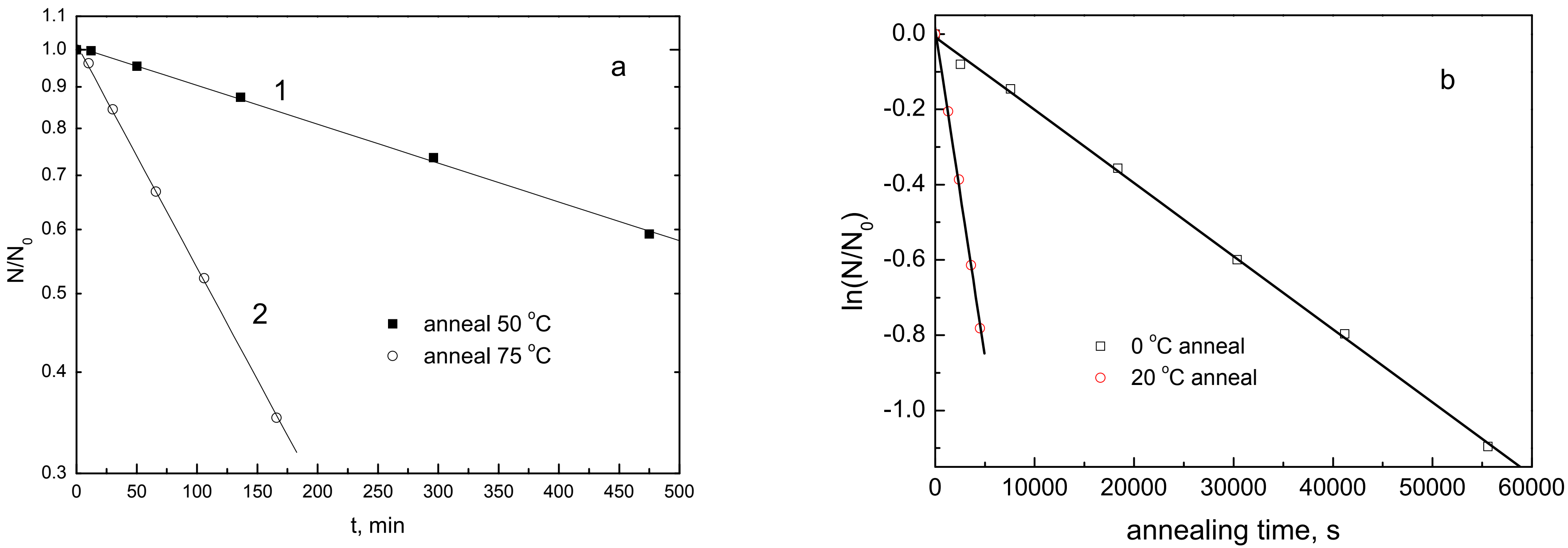

Fig.2. Annealing kinetics E0 peak in STFZ (a) and DOFZ (b) detectors

Table 3
Impurity concentrations of standard and oxygen-enriched devices under investigation

Device acronym	**CA**	**CD**	**CE**	**CH**
Orientation	<111>	<111>	<100>	<100>
O-diffusion (h)	0	72	0	72
[O] (10^{16} cm^{-3})	≤3	12	≤3	31
[C] (10^{15} cm^{-3})	<3	3.9	<3	3.9

SIMS data from:
E. Fretwurst et al., Nuclear Instruments and Methods in Physics Research A Vol. 514 (2003) pp. 1–8.

Table 4
Estimation of oxygen and carbon concentrations in oxygen-enriched devices (CD diode)

Impurity	**SIMS**	**USSR**	**UK**	**USA**
[O] (10^{16} cm^{-3})	12	~20	~5	~2.5
[C] (10^{15} cm^{-3})	3.9	~14	~6.3	~4.2

Table 5
Estimation of oxygen and carbon concentrations in standard FZ devices (CA diode)

Impurity	**SIMS data**	**USSR calibration**	**UK calibration**	**USA calibration**
[O] (10^{15} cm^{-3})	≤3	~0.8	~1.8	~3.9
[C] (10^{15} cm^{-3})	<3	~1.6	~3	~2.5

CONCLUSIONS

It seems that to treat Ci annealing data in the interval 0-20 °C data of Markevich and Murin for oxygen content determination are most appropriate.
It seems that to treat Ci annealing data in the interval 0-20 °C data of Tipping and Newman for carbon content determination are most appropriate.
The ratio between capture radii seems to be dependent on temperature and in the interval 0-20 °C it is close to unity.